Keywords: Woven, Knitting, Sports Garments, Sportswear, Performance, Functional Clothing, Innovation,

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Functional Clothing

Chapter 4: Fabrics for Performance Clothing

Jane Wood and Dr Tasneem Sabir

Fabric and its Application in Functional Clothing

There are many ways in which fabrics can be constructed, however, generally, fabrics can be categorised into three basic structures; woven, knitted and non-woven (Eberle et al., 2008). Each of the structures has its own attributes and drawbacks and careful selection is required to ensure the optimum performance is attained for the end user.

In the field of sports and performance wear, woven fabrics dominated early developments as the yarns available were of natural origins and therefore relatively coarse in terms of yarn count. Silks, cottons and wools were all popular as they imparted both protection and performance properties in varying degrees alongside desirable tactile features. However, they were not without their drawbacks and many limitations were apparent (Sule et al., 2007). Swimwear was particularly difficult to produce as the natural fibres absorbed moisture readily, leading to garments that quickly sagged and moved out of shape (Gedeon, 2007).

Around the time of the Second World War, synthetic fibres were developed to such a degree they became accessible to the mass market. The relatively high durability and low cost of the majority of synthetic fibres made them an appealing option to the consumer (O'Mahony and Braddock, 2002). Whilst most widely available synthetics lacked appeal in sportswear due to their poor breathability and handle, there was one manufactured fibre that had a major impact on sportswear fabrics.

The creation of Lycra^R revolutionised woven fabrics and saw the dawn of a new era in terms of woven close fitting garments due to their newly found elastic properties (Invista, 2013). By the time of the 1972 Munich Olympics, swimwear had been developed using Lycra^R containing knitted fabrics (Stefani, 2012). This sparked a trend in the widespread use of knitted fabrics with improved stretch throughout the sportswear industry.

As technologies developed and the synthetic fibre market became more advanced, the ability to produce extremely fine synthetic filaments encouraged the progression of knitting technology. In conjunction with the advances in synthetic fibres to enhance comfort properties, knitted fabrics became the popular choice for many sports apparel applications. Knitting is seen as the third largest fabric structure after woven and nonwoven structures. In recent times, advances in the technologies of fabric creation, alongside the use of innovative yarns and fibres, has seen interest refocus on woven fabrics, with many new applications being explored within the sports apparel market.

Basic Structures and their Influence on Sportswear Performance

Conventional Woven Structures

The earliest known method of fabric creation is the woven structure. The earliest woven constructions were those formed from reeds, leaves or bamboo in order to make mat type structures from which rudimentary designs could be fabricated.

Conventional woven fabrics are constructed from two sets of yarns, a warp (vertical) set and a weft (horizontal) set which are interlaced at right angles to each other to form a sheet structure. The regularity with which the yarns interlace determines the nomenclature and influences some of the basic properties of the weave. The most basic woven structure is the plain weave, which involves the interlacing of alternate warp and weft yarns as shown in figure 4.1.

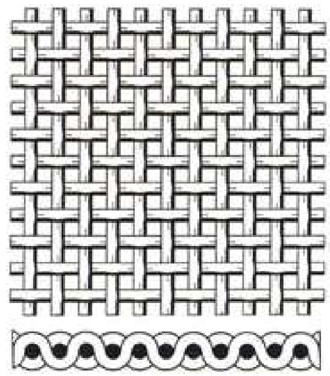


Figure 4.1 Formation of Loops to created Courses and Wales (Eberle et al., 2004)

This structure, although the most basic, is the most commonly found weave in apparel due to its relatively low cost, speed and ease of manufacture alongside its versatility (Elsasser, 2010). Twill and satin weaves are also found in apparel and are used to give both surface interest and to impart specific properties such as durability (twill) and drape (satin) to the structure.

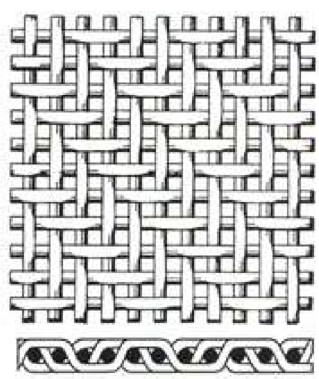


Figure 4.2 Twill Weave Structure (Reference Needed)

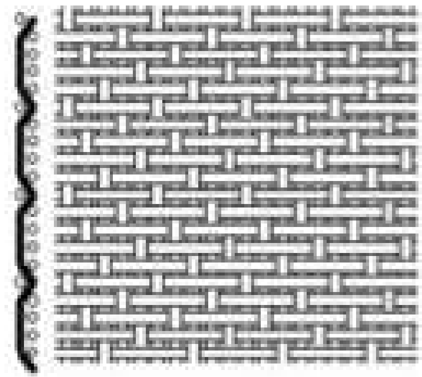


Figure 4.3 Satin Weave Structure (Reference Needed)

It could be suggested that woven fabric construction itself does not have to be complicated in order to achieve fabrics displaying high performance. Fabrics created using a basic woven construction can be engineered for a multitude of end uses by clever selection of fibre, yarn and finishing techniques.

One of the earliest types of plain woven fabric known for its protection of the body against wind and moisture is known as Ventile. This fabric is a 100% long staple fibre cotton, densely woven basket weave construction (a version of plain weave). When in contact with water, the cotton fibres swell, closing any gaps in the woven structure to such a degree that relatively high pressure is required for liquid water to penetrate through to the skin. This imparts a degree of waterproofing to the fabric without any type of chemical finish. The gaps are still sufficient for water vapour to pass from the body to the outer environment, thus allowing the body to 'breathe' and be comfortable (Chaudhari et al., 2004).

Woven structures such as twill and satin have been developed for specific sportswear applications (racing driver suits) by using a blend of carbon, polyester and cotton fibres

(Abd El Baky et al., 2011). However, it was shown that the selection of the weave structure was of secondary importance to that of the fibre. In this case, the carbon fibre and excellent heat resistance rather than the weave structure imparted the specific performance properties required.

Conventional Knitted Structures

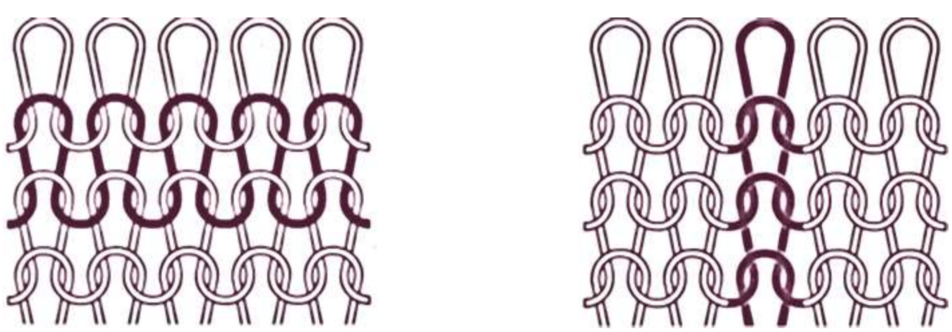
Sports development encompasses improving the athletes performance by seeking ways of studying the human body and engineered garments. By creating innovative fibres and fabrics, the textile industry has supported the developments of functional clothing to enhanced the levels of athlete’s performance. The early adoption of knitted structures were by luxury brands to created figure hugging garments. The early part of 80s saw the introduction of knits to the sportswear market (El-Hady and El Baky, 2010). Although many of the fabrics produced used high quality fibres, yarns and complex structures, these helped to improve the functional properties of garments for the sportswear market. In recent years, the developments of both knitted and woven structures have appeared in the same garments, although many of today’s highly engineering garments have opted for the knit structure. This section of the chapter will provide the reader with basic terminology and structural details of knitted fabrics with their related properties. It further explains the application of knitted fabrics in performance sports garments.

Classification of Knit Structures

In contrast to woven fabrics, which can be defined as structures developed from the interlacing of yarns; knitted fabrics are those derived from the interlooping of yarns (Choi and Powell, 2005). Circular and flatbed knitting machines, using needles, distort yarns into loops, which are then interloped with each other to form the knit structure.

Knit structures were once thought of as inferior to their woven counterparts due to their relative instability – however, innovations in both yarn and machine technologies have elevated knitted materials to, in some cases, have properties that far outweigh those offered by woven structures. Many brands in today's global market are utilising knit structures due to their advance properties (Power, cited in Fairhurst, 2008). The rise and popularity of knitted fabrics in sportswear applications offer properties that lend themselves to casual leisure activities to extreme performance sports.

Knitted fabrics fall into two categories – warp and weft knitting, formed from a single yarn or from many yarns in either a weft-wise or warp-wise direction. When the loops intermesh with another, this is called a loop-stitch. These loops interlock to form courses and wales (figure 4.4) eventually resulting in a final product or a garment.



Courses Wales

Figure 4.4 Formation of loops to created courses and wales (Eberle et al., 2004)

Weft knitting

This form of knitting was commonly associated to hand knitting. Weft knitting is a method where a single yarn is used to generate a row of loops. The interlooping yarns are carried horizontally to form loops in rows (figure 4.5).

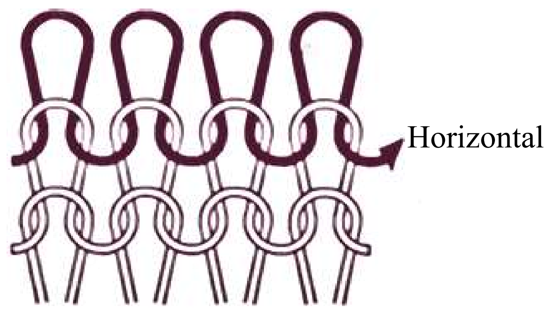


Figure 4.5 Weft Knit Structure (Eberle et al., 2004)

Weft knit structures can use multiple of yarns to create complex pattern designs. Generally, the properties of weft knitted fabrics are soft, pliable and have good handle and drape. These materials have a tendency to unravel course by course and are extremely stretchy. General end-use for weft knitted garments are socks, T-shirts and sweaters, cardigans and outwear garments (Gao, 2009). Most materials produced are in a tubular form.

Warp knitting

In warp knitting, yarns are attached to the top of the machine, running vertically to create the knitted loops in a lengthwise direction, interlooping the yarns to form columns of loops. The formation of loops and properties differ significantly between each of the warp knitted structures.

Gajjor (2011) explains how changing the sideway motion or shogging movement of the guide-bars create the different stitches in warp knitted fabrics. These materials have little stretch and less likely to unravel. Warp knit structure are stronger and stable than weft knit structures. End-uses of these structure are technical applications, sportswear and underwear. Most warp knit materials are manufactured flat or in open width form.

Vertical

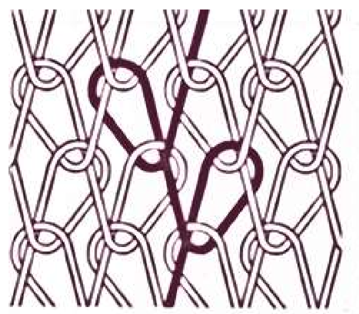


Figure 4.6 Warp Knit Structure (Eberle et al., 2004)

Properties of Warp and Weft Knit Structures

The properties of both knitted warp and weft structures are highly dependent on the fibres, yarn type and constructional details. Due to the mobility of the loops in weft knitted structures, this excels the thermal properties. The demand of many garments, in particular sportswear, requires the fabric to bend and stretch freely. This is achieved by the constructional details provided by the knitted structures offering excellent elasticity, comfort and absorption ability (Chen, 2013). Warp knitted fabrics are general more stable than weft knit structures. However, weft knitted structures often encounter problems with dimensional stability; as the mechanical stress applied during washing can distort the fabric. Conversely, the application of finishes to the surface of the fabrics can minimise this behaviour.

Weft Knitted Structures

Weft knit structures offers plenty of movement and flexibility although due to their unstable structures can have a limited appearance and can sag unless suitably laundered and stored. The basic weft knit structures are Jersey knit (Plain), Rib knits, Purl knits and Interlock. These structures make-up many of the fabrics in today's apparel market.

Jersey Knits (Plain)

Jersey (plain) knit is the most economical structure to produce. These structures can be manufactured as light-weight to heavy-weight fabrics. The structure allows the fabric to stretch both crosswise and lengthwise – more so in the crosswise direction and has good drape. This structures is generally associated to T-Shirts.

Rib Structure

The constructional details of these fabrics are complex making it slower in production than plain single jersey. The properties of the fabrics include elasticity and stretch, considerably in the crosswise direction. This benefits an important feature in fashion garments.

Purl Structure

Purl fabrics are considered the most expensive to manufacture of the basic knits as it requires more production time. Purl fabrics have good stretch in all directions, however due to the elasticity, the fabrics can be stretched out of shape easily. The fabrics can be quite decorative and used heavily in children's wear.

Interlock

This is a stable fabric structure with limited crosswise stretch. Nowadays, this structures is rarely used in fashion garments (Power, cited in Fairhurst, 2008) and has found a place in technical textiles.

Warp knitting Structure

Tricot and Raschel are two types of knitting machines, which produce the vast amount of warp knitted structures in textile industry. Many of the fabrics correspond to the two machines. Tricot is associated with plain tight structures, whereas Raschel lend themselves to open, jacquard and fancy structures.

Tricot Knits

Tricot knitted fabrics account for most of the warp knit structures. It is essential that high quality, uniform filament yarns are used to create these structures. The characteristics of these structures are uniform in weight and appearance, displaying a tightly knitted structure. Tricot fabrics have little stretch.

Raschel Knits

Raschel fabrics are similar to tricot, but are available in a variety of patterns and textural design. The structure allow for heavy yarns to be used and create open structures.

Application of Fabric Structures in Sportswear

During the 1980s, this period saw a rise in modern sportswear (El-Hady and El-Baky, 2010). By a single fibre or by simply coating the fibre/fabric provided the functional characteristics for many garments in sporting activities. Over time, the creation of innovative fibres and complex structures have allowed for a wide variety of properties to incorporated in one single garment. The application of knitted fabrics in sports garments have increased due to the demand of stretchable, wrinkle-resistance and snug-fitting garment. With advances in digital technology, this has opened the market to create innovative patterns, efficiently and practically. As the living standards of people increase, their leisure activities have also seen a growth, where people are more health conscious. The demands for multi-functional clothing to incorporate comfort and health benefits are on the rise (Liu and Liu, 2012).

In any sporting activity, many factors need to be considered to perform to the optimum level. Three main attributes in the success/failure of a sport relates to; (i) the athlete's ability (ii) equipment and facilities and; (iii) engineered clothing (Chowdhury et al., 2012 and Yan et al., 2011). According to Feng and Liu (2012) and Onofrei et al., (2011) the most important characteristic of functional clothing is to create a stable microclimate close to the skin to support the body's thermoregulatory system in any physical environment. Tactile (hand) and aesthetics (appearance) are considered important qualities in garments (Emirhanova and Kavusturan, 2008). Understanding the fibre properties and the effects on the fabric is fundamental to the garment. Based on the above characteristics, knitted fabrics are commonly preferred (Milučionienė and Milašienė, 2013).

Some of the well-known engineered garments have amalgamated both science and technology to create functional sportswear. The intricate structures combined with material composition meet the demands of sportswear designs and performance. The structural details and mapping of the properties have led sports companies concentrating on different aspects of the body. Nike (2013) launched a range of warp knitted garments to provide breathable and cooling zones within their sports garments. The research and development team mapped the zone areas of females. The data generated allowed an engineered warp mesh structure to apply heated zones to certain parts of the torso.

Figure 4.7 Nike Pro Elite Woman's Workout Garment (Nike 2013)

X-bionic was another recognized sportswear company specializing in incorporating aspects of nature in their most innovative and highly functional clothing range. In 12 years, X-bionic have revolutionized functional clothing (X-bionic, date). Most of the garments manufactured use intricate warp knit structures to create muscle control, support tissue, partial compression to name a few. Figure 4.8 illustrates the Trick technology to regulate the body temperature. The sophisticated mapping of the tightly knitted warp structures sends signals along the spine to the brain enabling the body to cool through perspiration.

Figure 4.8 X-bionic Trick Technology (Innovationintextiles.com, 2013)

Woven structures have found a place in sports apparel as ‘outer’ or protective fabrics, rather than those lying in direct contact with the skin. Woven fabrics have proven particularly useful in protection against wind and rain, whilst allowing breathability to enhance wearer comfort. However, it has been the development of fibres, yarns and finishes rather than the woven structure itself that have led to technological advances.

Microfibre woven fabrics are commonly used as ‘soft shells’ in the sporting activities. The ‘shell’ is the garment forming the outermost layer of clothing, whilst the ‘soft’ is attributed to the tactility of the microfiber fabric. The development of microfibers has allowed the principle of the densely woven fabric structure to be further explored. Developments by companies such as Invista (2013) are typical examples:

Coolmax[R] is a microfiber polyester with a 'grooved' cross section which allows moisture to flow away from the body; whilst Thermolite[R] is another polyester based microfiber, this time with a hollow cross section which imparts insulation properties to the woven structure (Advansa, 2013). The microfibres themselves are pleasant to the touch whilst the polyester imparts strength and durability to the fabric. Additionally, the fineness of the filaments enables a tightly woven structure to be developed, which can impart properties such as windproofing, without compromise to handle or breatheability (Braddock, 2005).

Wovens vs. Knits – A Case Study: The Speedo Story

Speedo is a manufacturer and distributor of swim apparel, with their head offices in Nottingham, UK. They have been strong innovators of swimwear and are the sponsor of several national swimming teams. Their innovations in swimwear began in 1932, focusing on garment design, with Arne Borgs racer back swimsuit (Stefani, 2012).

Figure 4.9 Arne Borg Racerback Swimsuit (History, 2013)

Speedo became synonymous with swimsuits and the developments of new fabrics and the reduction of drag and turbulence saw the introduction of swimwear bodysuit, were once the swimsuit covered less, now the garments were covering the entire body (Stefani, 2012

Speedo created one of the most exciting swimsuits known as the 'Speedo Fastskin™'. The Speedo Fastskin™ was designed to enhance performance of the swimmer by reducing the effects of friction drag in the water (Toussant et al., 2007). The Fastskin™ 'sharkskin-based design' fabric was developed in conjunction with Fiona Fairhurst (a former competitive swimmer) and was a knitted base structure with features that were said to mimic sharkskin to improve the speed of the wearer in the water. It was marketed as *'the world's fastest swimsuit'* (Stefani, 2012 pg 14).

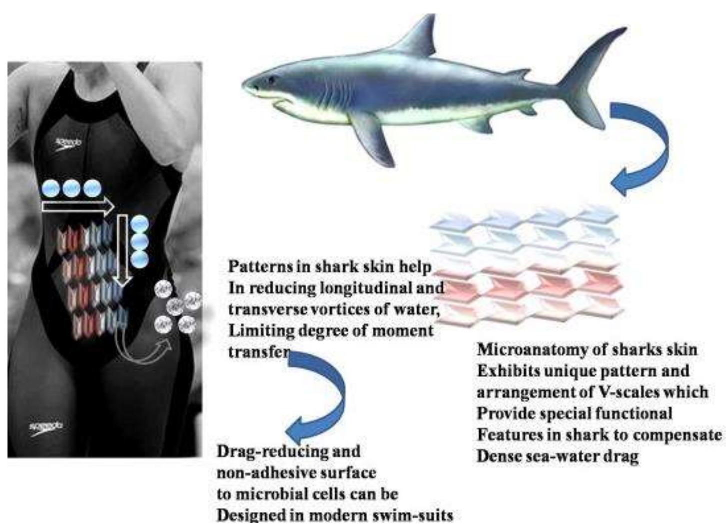


Figure 4.10 Sharkskin swimsuits design (Singh et al., 2012)

The product was successful and saw improvements in racing times for the wearers. The Fastskin™ was considered a super lightweight suit and saw Michael Phelps beat his own 200m Fly World Record wearing the garment (Speedo, date?). However, the Speedo development team realised that there was still room for further development.

A woven fabric ‘LZR Pulse’, which Speedo claimed to be ‘the worlds lightest woven swim fabric’ was the next innovation, launched in 2008 (Speedo, 2013). The fabric was a densely woven microfiber nylon / elastane blend (Rodie, 2008). Containing two way stretch, it was highly compressive and the areas of compression were concentrated in the suit at critical points to alter body shape and allow a more streamlined form in the water. Additionally the fabric was treated using nanotechnology to improve its water repellence / absorption and the enhanced chlorine resistance meant that any degradation of properties such as compression or strength were kept to a minimum.

Clever garment engineering techniques, such as bonded seams flowed with the contours of the body to further enhance the reduced drag resistance in the water. However, a major ‘drawback’ of the suit was that swimmers reported it took up to 20 minutes to dress due to the tightness of the fit. The Speedo LZR Pulse fabric was used in competition and swimmers wearing the suit broke a total of 46 world records, whilst at the Beijing Olympic games, 94% of the swimming races were won by competitors wearing suits made from the fabric (Stefani, 2012). This led to the international swimming federation,FINA, imposing a controversial international ban on the ‘performance enhancing’ swim suit (BBC, 2009; Marinho, 2012).

Future Developments in Woven and Knitted Fabrics

By merging both woven and knitted fabrics upgrades the wearability and design of a sports garment (Chen, 2013). The textile industry is constantly seeking ways of improving garments to enhance performance levels. By combining material engineering and clothing science has assisted in the physiology and physiological well-being of an athlete. The future developments in woven and knitted fabrics generally lie in its most basic element, the fibre and then further into the complex composites.

Fibre Developments

Developments in sportswear are to study and understanding of its core material, the 'fibre'. Variations in fibres are based on their dimensions (fineness/length), shape and constitution to increase functional properties required for the sports market including anti-bacterial, moisture regulation, comfort, breathable, soft and durable, leading to smart and functional designs. Nanotechnology according to Nanostart.de (2013) brings about transformational change to the new era of sustainable energy. Engineered at the molecular level (1 to 100+ nm), the fabrics are manipulated to repel dirt, grease and oil (Wu and Li, 2006). Nanotechnology is being incorporated more in sportswear by reducing the stresses applied to the body or to improve comfort. Nanotechnology can improve textiles by creating a barrier against elements such as dirt, soiling and chemical attacks. Nanotechnology has also seen application in areas of medical and protective clothing. Nano-enhanced materials have incorporated silver to inhibit the growth of bacteria and reduce odor (nano.org.uk, 2010). One of the most novel nanotech textiles were seen in the sharkskin suit worn by the Olympic Swimmer Michael Phelps. The suit include a nano-plasma layer which significantly repelled water molecules and enhanced the swimmer's glide through the water (Nanomagazine, 2010). Nano-optimised particles have also been incorporated in the latest generation of ski clothing, aqua and golfing.

Fabric Developments

Variation in fabric constructions can be achieved by three methods. One method is by altering the weave or knit construction. This can take the form of complex structures of woven and knits to more elaborative technical structures seen in 3D and spacer fabrics. 3D weaving is seen as the next big step in development of woven fabric structure. 3D weaving can be defined as *'A fabric, the constituent yams of which are supposed to be disposed in a three-mutually-perpendicular-planes relationship'* (Khokar, 2001 pg 196). This can be taken to mean any one of a variety of structures, but is commonly accepted that the structure is not of the 'flat' planar type usually associated with woven materials used for garments. This type of woven structure has a noticeable 'depth' to its structure, in effect, adding a third dimension to the fabric (Chen & Hearle, 2013). Another way of visualising a 3D woven structure is that of a pre-formed shape. This technology is predominantly used in highly engineered functions, such as air foils, fan blades and even car manufacture (Ceurstemont, 2011). It has also found use in ballistics protection and body armour (Kaufman, 2012).

Many sportswear products are derived from sources that are associated with strong engineering backgrounds, such as the automotive or aeronautical industries. The development of the Speedo LZR Pulse fabric used techniques more commonly found in the development of cars to assess frictional drag of fluids. It is therefore reasonable to assume that 3D fabric could have potential in the sportswear apparel market. Ballistic protection has been explored in depth using 3D fabrics (Chen & Hearle, 2013); this could easily translate into protective wear such as shin pads for cricket, helmets for cycling or body armour type apparel used in American football (Marshall et al., 2002). Chen (2013) reports that even sports apparatus has been explored using 3D woven fabrics, with the development of lightweight golf clubs.

According to Sheikhzadeh et al., (2010) spacer fabrics can be described as two layers of knitted fabrics joined together by monofilament yarn.

Figure 4.10 Structure of a Spacer Fabric (Chinta and Gujar, 2013)

The fabric can also be referred as a sandwich with the third layer tucked between the two layers. The unique feature of the mid layer can take the form of tubes, pleats or engineered form. The built in pockets allow the zones to create layers of air, which act as insulation with thermoregulation effects. In the sportswear industry, warp and weft faced spacer fabrics can be found in applications such as functional clothing, sports shoes, shoulder pads and knee and elbow protectors (Chinta and Gujar, 2013). Figure 4.11 illustrates a spacer fabric constructed by Mayer & Cie. This is double jersey structures, which is very stable and has seen its application in shoe manufacturing.

Figure 4.11 Technit D3 Spacer Fabric (Hunter, 2009)

"New science that studies nature's models and then imitates or takes inspiration from these designs and processes to solve human problems". (Benyus, 2002). Biomimetics is a science of using nature to solve human problems, creating innovative products. Nature is a fantastic way we can mimic the living in sports clothing. A well-known example includes Velcro – a biomimetic examples inspired by burs. Moisture management is extremely important in the sportswear market. The opening and closing of vents in clothing have mimicked the pinecones. As illustrated in Figure 4.12 Nike introduced clothing incorporating the pinecone effect where the likes of Maria Sharapova and Roger Federer wore at the US Open 2006 Tennis Gland Slam.

Figure 4.12 Maria Sharapova and Roger Federer with Nike Macro React (Shikya, 2010)

Composite fabrics use a combination of different fibres or by combining different fabrics construction in one garment. Cloverbrook are leaders in performance fabrics. A number of their garments include two-layer cellular construction where each layer is composed of a natural and synthetic fibre. Dry wool is one of the latest fabric developments from Cloverbrook using a combination of merino wool and synthetic fibres, leaving the body dry and comfortable.

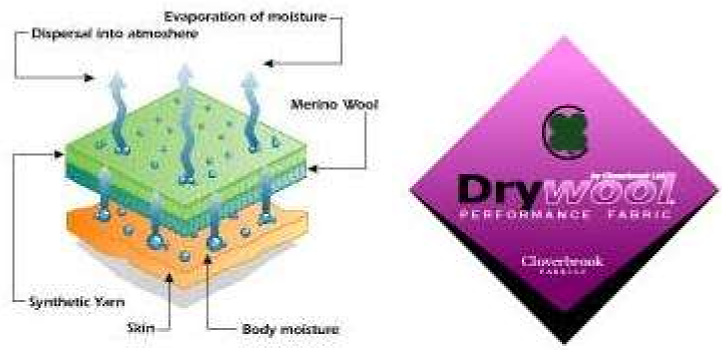


Figure 4.13 Drywool by Cloverbrook (Cloverbrook, 2013)

Conclusions

Early sportswear was dominated by natural origins like silk, cotton and wool woven into garments with a degree of performance. With the development of synthetic fibres came about the creation of sportswear using knitting technologies. With advances in comfort properties has led to the industry embracing knitting as a popular choice of constructional methods. However, interest has been refocused on woven fabrics and using both constructions, many sportswear applications have improved performance.

Woven materials are classified as the interlacing of yarns at right angles. Basic structures include plain, twill and satin. Each of the weaves has its own benefits and drawbacks. knitting has created the latest generation of sophicated clothing with many able to control muscle tissue, compression leading to increased oxygen and blood flow, and comfort. Knitting similar to woven fabrics has basic constructions in warp and weft direction. Many of the fabrics today are warp knitted which have been cleverly engineered to incorporate different degrees of tension to improve the optimum level of an athlete.

Woven and knitted structures both share benefits and limitations but the combination in one garment has led to the most successful and innovative garment in the sportswear industry the 'Fastskin™' sharkskin suit. The future in sports developments is to engineer garments that allow improved performance and functionality but remain aesthetically pleasing.

The use of protective clothing becoming more widespread – now in sports where traditionally not used – sailing (death of Bart Simpson – (Alexander, 2013))

Body toning fabrics http://www.innovationintextiles.com/fila-launches-body-toning-apparel-with-lycra-sport-fabric/ **not sure what this is?????**

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